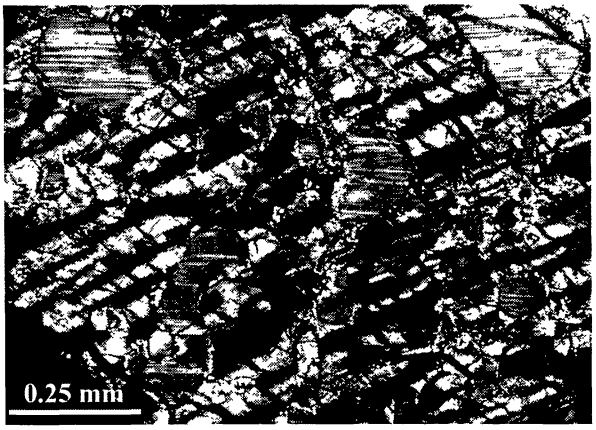

Fig. 1.

isolated from one another, are in optical continuity (Fig. 1). They often show parallel striations (twinning?) at a high angle (~35° in Fig. 1) to the exsolution lamellae in the oikocryst. They also have irregular rims of pigeonite. Striations in the augite grains continue through the pigeonite. The pyroxene oikocrysts also enclose much less abundant grains of olivine and chromite, with secondary reduction rims.

Both the augite lamellae and the poikilitically included augite grains are homogeneous. Their compositions are identical: mg = 79.5 ± 0.05, Wo = 33.1 ± 0.3. The opx lamellae contain submicrometer-width lamellae of augite, but on the scale of EMP analyses are homogeneous: mg = 78.4 ± 0.04, Wo = 4.2 ± 0.1. I estimate the bulk composition of the oikocrystic pyroxene to be mg = 78.7, Wo = 13.2. Pigeonite is highly variable in composition: mg = 77.0–91.3 (avg. ~82), Wo = 5.5–13.7 (avg. ~9). The contents of Cr_2O_3, MnO, TiO_2, and Na_2O range to both higher and lower values than those of either the opx lamellae or the calculated bulk oikocrysts, and show no compositional trends. The contents of Al_2O_3 are lower than those of either the opx or the augite.

Interpretation: The texture of LEW 88774 and other bimodal ureilites is similar to that of heteradcumulates of terrestrial layered igneous complexes, in which poikilitic crystals, grown from pore liquids, surround cumulus crystals [7,8]. The texture of LEW 88774 resembles, in particular, reaction textures in such cumulates, in which the poikilitic crystals enclose isolated, optically continuous remnants of once single cumulus crystals. Such textures result from resorption/replacement of primocryst material by reaction with pore liquids [8–10].

Lewis Cliff 88774 may have formed by reaction of an olivine-augite-chromite-(graphite) assemblage with an opx-saturated liquid. Most of the olivine and much of the augite was resorbed, and the liquid then precipitated intermediate pyroxene around their remnants. The pigeonite rims probably formed in a later, solid-state reaction, possibly reduction. The presence of chromite in the primary assemblage suggests that it may have been a cumulate [1], analogous to chromite-rich zones of terrestrial layered igneous complexes [11]. A melt component in LEW 88774 is also suggested by its bulk composition [4] — high REE, Ca and Al, and superchondritic Mn/Mg [12]. Details of the proposed reactions and the origin of the pore liquid will be discussed.

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APATITE CONTROL OF CHONDRITIC ACTINIDE CHEMISTRY? J. S. Goreva and D. S. Burnett, Mail Code 100-23, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena CA 91125, USA (julia@gps.caltech.edu)

The solar system Th/U is regarded as about 3.7, and ratios close to this are directly measured in a wide variety of planetary materials. Consequently, given that chondritic composition is regarded as solar for refractory lithophile elements, it is surprising that some ordinary chondrites show high ratios (6–6.5). We set out to understand the origin and implications of these anomalies, first by establishing that we had samples of the anomalous material using high accuracy isotope dilution, ICPMS measurements of Th/U. Our three samples of Glatton (L6) were not anomalous (Th/U from 3.71 to 3.84), but for 12, typically gram-sized, samples of Harleton (L6) we find a *range* of Th/U from 2.5 to 6, a greater range of Th/U in one meteorite than in all previous ordinary chondrite analyses. Moreover, Fig. 1 shows (1) the Th/U variations linearly correlate with 1/U, suggesting two component mixing; (2) other literature analyses follow the Harleton trend.

It is well known that U and Th are concentrated in apatite and merrilite in ordinary chondrites with distinct Th/U (Fig. 1). One would expect that mixtures of these phases with inert material would produce wide scatter on Fig. 1. The observed correlation is thus a surprise. However, a simple mixing model (line in Fig. 1) describes the trend well by assuming (1) apatite is the high-U component; (2) the low U component is merrillite; and (3) a fixed-proportion mixture of 1% total phosphate and inert material. Variations in apatite/merrillite (0.3–0.03) with fixed total phosphate content produce the trend. Supporting this interpretation, we observe a high modal apatite/merrilite for Harleton relative to average chondritic proportions. Petrogenetically, Cl appears to control the U, and to a lesser extent, Th, distributions. The heterogeneous Cl distribution in ordinary chondrite parent bodies causes the Th/U variations. Somewhat ironically, *the distribution of a low Th/U phase (apatite) explains the high Th/U anomalies!*

Rocholl and Jochum [1] previously found a similar correlation for carbonaceous chondrites, but with different lines for CI, CM, and CV. They suggested apatite as the high U component and we have no better alternative. Apatite has been reported in carbonaceous chondrites, but it is unclear that apatite abundances and actinide contents are sufficient to produce the Th/U correlations. Diluted merrillite is an unlikely low U component for carbonaceous chondrites. It may be better to regard this as a mixture of high Th/U CAI material with either inert material or a solar nebula component with solar actinide abundances. The required constant mixing ratios are perhaps surprising since chondrules constitute a significant actinide reservoir for unequilibrated chondrites, but perhaps these could be the required low U component.

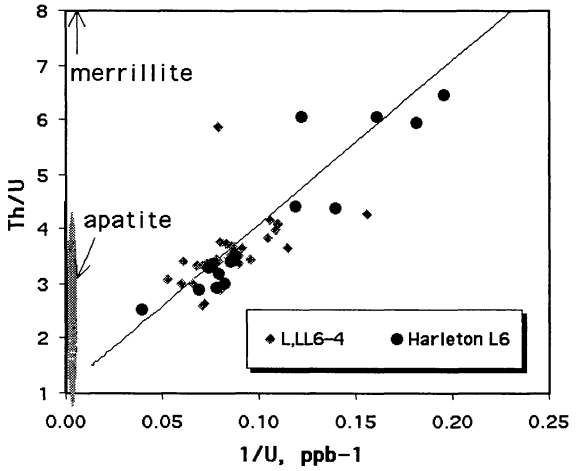

Fig. 1. Whole-rock ID data.

There are testable predictions of the above interpretations: (1) relatively constant P contents in our ordinary chondrite samples regardless of Th/U; (2) Th/U <2 in ordinary chondrite apatite; and (3) high actinide/P in leachable fractions of carbonaceous chondrites.

The solar Th/U ratio plays a major role in cosmochronology, but accurate knowledge is required. If Th/U variations in equilibrated ordinary chondrites are entirely due to relatively local actinide redistribution, controlled by Cl, then a more accurate solar system Th/U is obtained by averaging high-accuracy actinide analyses.

References: [1] Rocholl and Jochum (1993) *EPSL, 117,* 265–278.

MINERALOGY OF THE 1998 ASTROLABE ANTARCTIC MICROMETEORITES COLLECTION. M. Gounelle[1], M. Maurette[1], C. Engrand[1], F. Brandstätter[2], and G. Kurat[2], [1]Centre de Spectrométrie Nucleaire et de Spectrométrie de Masse, 91405 Orsay Campus, France (gounelle@csnsm.in2p3.fr), [2]Naturhistorisches Museum, Postfach 417, A-1014 Vienna, Austria.

In 1998 we recovered new Antarctic micrometeorites (AMMs) on the glacier Astrolabe [1] 3 km from our previous Cap-Prudhomme (CP) sites [2]. The major objective of this collection was to detect a possible variation in the composition of the AMMs flux at these two sites that would confirm that which was discovered at the South Pole [3]. For this purpose we extracted 86 micrometeorites from the 50–100 and 100–400-μm-sized fractions of the 26/01/98 daily collect. Their texture and mineralogy were characterized using SEM and electron microprobe.

Antarctic micrometeorites (AMMs) have been classified into crystalline (xtal), fine-grained hydrous (fgh) and partially melted/dehydrated scoriaceous (sco) types. Scoriaceous AMMs are the most abundant in the Astrolabe 100–400-μm-sized fraction (xtal 18%; fgh 35%; sco 47%) whereas fine-grained hydrous AMMs dominate the 50–100-μm-sized fraction (xtal 16%; fgh 61%; sco 23%).

Olivines and pyroxenes are found in all micrometeorite types. Olivines split into two compositional groups: a forsteritic one (Fo_{95-100}) and a more Fe-rich population (Fo_{70-85}). Pyroxenes are as abundant as olivines and are dominated by low-Ca pyroxenes with compositions ranging from $En_{64}Wo_2$ to $En_{98}Wo_1$. Diopside ($En_{47}Wo_{45}$) and high-Ca pigeonite ($En_{82}Wo_{17}$) are rare. Partially dehydrated and pristine phyllosili-cates are common among fine-grained hydrous Astrolabe AMMs. Major-element composition suggests that ~20% of the phyllosilicate phases are made of serpentine and ~80% are mixtures of serpentine and smectite. The Al_2O_3 content in phyllosilicates ranges from 0.7 to 17.0 wt% with a most frequent value of 2.5%. The Mg content of phyllosilicates varies within a broad range (mg* = Mg/(Mg + Fe) from 0.13 to 0.81, with average at 0.48). One micrometeorite is a refractory inclusion consisting of spinel rimmed by serpentine with a composition close to that of cronstedtite (MgO 5.3, Al_2O_3 2.0, SiO_2 22.8, FeO 55.8 wt%). Magnetite is common and occurs as a thin shell enclosing AMMs as well as subhedral to euhedral crystals often associated with phyllosilicates. Metal is rare and occurs mostly as kamacite droplets in olivines. Submicrometer sulfides (mainly pyrrhotite) are rare. Sodium chloride is abundant at the AMMs' surface and an unidentified Fe-K sulfate occurs commonly both at the surface and in AMMs' interior. No chondrule was found.

The mineralogy of micrometeorites from the Astrolabe collection is broadly similar to that of the Cap-Prudhomme collections [4]. Indeed, Astrolabe AMMs consist of an assemblage of phyllosilicates and anhydrous phases; they show a high pyroxene/olivine ratio (~1) and a strong depletion in chondrules.

Three observations make, however, Astrolabe AMMs slightly distinct from CP AMMs: (1) fgh Astrolabe AMMs from the 50–100-μm-sized fraction are three times more abundant relative to scoriaceous than in CP AMMs; (2) Astrolabe AMMs contain chlorides and sulfates very rarely observed at Cap-Prudhomme; and (3) phyllosilicates in Astrolabe AMMs are dominated by a mixture of serpentine and smectite (association typical of CR2 and CI1 carbonaceous chondrites) instead of being dominated by serpentine [4], a mineral typical of CM carbonaceous chondrites. The first and second observations could result from modifications of our collection procedure [1] and terrestrial contamination due to marine aerosols, respectively. The third observation confirms that AMMs show similarities (and differences) with all three hydrated carbonaceous chondrites groups and not only with the CM one [4].

In summary, no major compositional variation in the micrometeorite flux on the short timescale of 1000 yr (corresponding to the age difference of the Astrolabe and Cap Prudhomme sites) was found.

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CARBON, NITROGEN, AND NOBLE GAS STUDY OF DARK INCLUSIONS IN THE WELLS ORDINARY CHONDRITE. M. M. Grady[1,2], M. K. Weisberg[3], A. Verchovsky[2], I. A. Franchi[2], C. T. Pillinger[2], and M. Prinz[3], [1]Department of Mineralogy, The Natural History Museum, London, UK (mmg@nhm.ac.uk), [2]Planetary Sciences Research Institute, The Open University, Milton Keynes MK7 6AA, UK, [3]Department of Earth and Planeteary Sciences, American Museum of Natural History, New York NY 10024, USA.

Introduction: The Wells LL3.3 ordinary chondrite (OC) is remarkable for the number and size of dark inclusions (DI) it contains [1]. A study [1] of one particularly large DI (DI-1; 5 × 5 mm across) reported approximately 2 vol% graphite in the inclusion. The O-isotopic composition of DI-1 plots on the Allende mixing line, suggesting that it is more akin to carbonaceous chondrites than the dominant OC host material. Likewise, the thermal history of DI-1 is different from that of its host. Thus DI-1 is an example of a meteorite within a meteorite, testifying to the complex processes of accumulation, brecciation, and reaggregation that occurred during early solar system history. Furthermore, the petrology of DI-1, with its graphite- and sulfide-rich matrix, implies that DI-1 is an unusual type of chondrite, possibly even unique among meteorites. Given the high graphite abundance, and the association of noble gases with graphite hosts in other meteorite groups, we decided to undertake a light-element stable isotopic investigation of Wells DI-1 to complement the petrologic study, and constrain further the origins of DI-1's parent.

Results: One chip from within DI-1 was analyzed for C, and a second was analyzed for N, Ar, and Ne. Results for the C experiment are shown in Fig. 1. DI-1 is indeed C-rich, containing 2.34 wt% C; the broad combustion temperature of 650°–900°C confirms that the C occurs dominantly as graphite, possibly with a range of crystallinities. The graphite has $\delta^{13}C$ of –6‰, very similar to the values for enstatite chondrites [2] and winonaites [3], but different from graphite in ordinary chondrites, which tends to be isotopically lighter with –15 to –17‰ $\delta^{13}C$ [4]. The inclusion contains 98 ppm N, with overall $\delta^{15}N$ ~ +5.5‰. There are two maxima in N release, the first between 600° and 700°C, of 12.5 ppm and

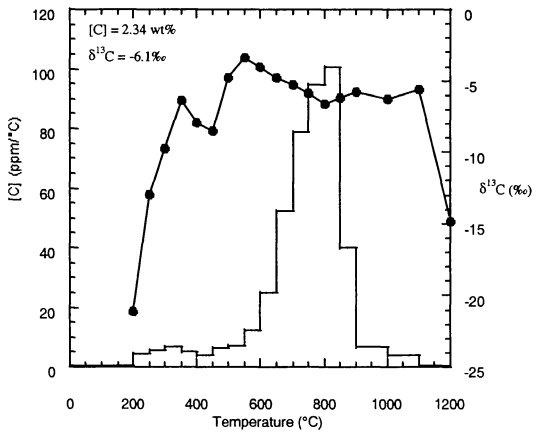

Fig. 1. Inclusion DI-1 from Wells.